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WORKING PAPER
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BEYOND PERSISTENCE:
UNDERSTANDING THE COMMITMENT OF PIONEERS IN
EMERGING FIELDS OF SCIENCE AND TECHNOLOGY

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Technology*

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Sloan WP # 3388-92

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BEYOND PERSISTENCE: UNDERSTANDING THE COMMITMENT OF PIONEERS IN EMERGING FIELDS OF SCIENCE AND TECHNOLOGY

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ABSTRACT

This paper examines pioneering scientists and the factors that influence their choice and persistence in an area of research, and compares their experience with those scientists who follow in their footsteps once the field becomes legitimated. Evidence is presented from an international survey of more than seven-hundred researchers working in the field of neural networks. After controlling for age and professional experience, the results of the analysis suggest that pioneers as a group are indeed different in both their motivations to enter and their persistence to remain in the field. In general, compared with other scientists, pioneers are more deeply influenced by the intrinsic intellectual appeal of the field and are less influenced by the social dynamics of the research community.

INTRODUCTION

Sociological investigations of scientific and technological communities have contributed a great deal to our understanding of the research and development process. One area of investigation at the genesis of the research process, is the question of why scientists choose to pursue the topic of research they do, embracing certain problems as important while disregarding others as inconsequential—the so-called “problem of problem choice” (Zuckerman, 1978; Gieryn, 1978; and Ziman, 1987). The answer to this question is pivotal to any explanation of the emergence of nascent fields of science and technology, as it lies at the very heart of the matter. For whatever reason, by choosing to apply their energy to one set of problems and not another, scientists can thereby steer the frontier of knowledge in new and different directions.

A common approach to unraveling the problem of problem choice is to distinguish between factors influencing scientists’ decisions that are internal and external to the

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scientific community (Cole and Cole, 1973; Zuckerman, 1978). Factors internal to science include both the cognitive and the social. Recognizing the influence of the cognitive side of the equation on problem choice, Zuckerman (1978) points to the importance of scientists' theoretical commitments and the feasibility of finding a solution. Scientists use their judgment in determining problems that are intellectually interesting and yet tractable given the state of current knowledge and technique. Recalling Medawar's theme of science as "the art of the soluble," Zuckerman quotes:

Good scientists study the most important problems they think they can solve. It is, after all, their professional business to solve problems, not merely grapple with them. The spectacle of a scientist locked in combat with the forces of ignorance is not an inspiring one if, in the outcome, the scientist is routed (Medawar, 1967).

Ultimately, scientists seek solutions to problems they perceive as significant to "science" and that have a good chance of being found, preferably sooner than later. But what is it that informs their judgment of what is indeed significant? The internalist argument holds that it is the logic of the scientific process itself that defines what is worthy of research; that science continually generates interesting problems of central importance to the cognitive structure of the field. By virtue of their training, scientists are equipped with a theoretical framework that guides their research agenda, allowing them to sort the wheat from the chaff. Problems at the periphery, problems whose answers are unlikely to contribute to the core cognitive structure, are perceived as less relevant. As a consequence of this line of reasoning, the problem of problem choice is purely one of intellect.

Suspicious of the self-contained nature of such an explanation, sociologists have sought to infuse an appreciation of the social dynamics of research communities, thereby making any investigation of problem choice behavior, well, a bit more problematic. Careful consideration must be given to the social interaction of researchers in influencing their choice of problems, including the effect of the reward system of science, communal norms, and social stratification. While it is true that, as Medawar claims, scientists grapple with nature, Merton (1938) and others have shown that they also grapple with each other. Rather than being made in an airtight cognitive realm, where "good" scientists *know* what the important problems are, the problem choice decisions of scientists are influenced by peer perceptions, competition for rewards, and the opinions of those scientists in a position of authority. Not only are scientists guided by theory in choosing problems, they are influenced by each other's problem choices and opinions regarding what is important—with the opinions of some scientists having more weight than others, given their stature within a research community.

Whether or not social influences reinforce or distort the cognitive influences on scientists' decisions is undoubtedly a critical question for the sociology of science. But clearly, the potential for distortion exists. The periodic exponential growth of scientific fields is well-documented (Crane, 1972; Menard, 1971) and not always easy to explain solely in terms of the underlying theoretical importance of a field. Rather, there is a tendency for "fashionable" problem areas to emerge in science (Barber, 1990; Crane, 1969; Hagström, 1965). Fashion is contemptible insofar as it represents a situation where scientists, guided more by perceptions of what is popular, mistake what is truly important to science. When popularity and importance do not coincide, scientists are given the choice of going along with their peers or breaking from the pack and reconciling themselves to less glamorous problem areas that are relatively starved for recognition and funds.

Attention to factors external to science that might nonetheless influence the problem choices of scientists was precipitated by an awareness of the tremendous industrial and military implications of science, and the attendant economic cost of what Price (1963) called "big science." The size and importance of frontier research in some branches of science necessitates a greater degree of administrative planning and control, which consequently places heavy constraints upon the freedom of individual scientists to choose their own research agenda. At the very least, scientists' perceptions of important problems are influenced by military and corporate imperatives; at the extreme, such imperatives have assumed control over the decision process itself and have thus made the problem of problem choice an organizational issue to be resolved in committee.

In sorting out the problem of problem choice, it is interesting to focus on a particular kind of scientist: one who pioneers a new field of research. Pioneers are defined here as those scientists who initiate and continue working in a field of research before it is widely perceived as significant, or perhaps even legitimate by their peers. Among the scientists who might choose to enter a new field, only a small portion will stay with it for the long term (Rappa and Garud, 1991). In his study of pioneering scientists in systematic zoology, Hull (1988) observes:

Scientists know that the struggle for acceptance is likely to be arduous, but they are not prepared for how long the process actually takes, nor for the amount of misunderstanding and misconstrual that inevitably ensues. Tenacity is as essential as originality in science.... Anyone promoting a nonstandard view must be prepared to write the same paper, fight the good fight, answer the same criticisms over and over again.... Failure in science is more often a function of the lack of resolve than anything else.

Thus, by virtue of their unconventional problem choices and unrelenting determination, pioneering scientists may ultimately lead the way in creating a new research specialty. Who are pioneers and what is it that informs their vision of what is significant research? Are they influenced in ways that are different from their non-pioneering colleagues in making their problem choices? Why do they persist in working in problem areas in the face of criticism from their peers? Given their central role to progress at the frontier of science and technology, the problem choice behavior of pioneers is worthy of careful examination.

Although the study of emergent fields of science and technology has occupied a prominent position in the literature, empirical research on the nature of pioneering scientists is limited, particularly with respect to their problem choice behavior. For example, in their account of the emergence of eight different fields, Lemaine, et al., (1976) aim at understanding factors that influence the rate, direction, and content of scientific development but do not single-out pioneers for systematic analysis. Even in more general studies in the sociology of science, pioneers have been curiously absent among the various kinds of scientists that have merited special attention. Instead, research has been focused on highly productive scientists (Long, 1978; Allison and Long, 1990), highly influential scientists, as determined by citation patterns (Cole, 1968), "marginal" scientists who make major contributions (Gieryn and Hirsh, 1983), and scientific elites, among whom Nobel laureates figure prominently (Zuckerman, 1967 and 1977). Although it may very well be the case, pioneers are not necessarily the most productive, nor the most influential, nor marginal, nor the most prominent of scientists. Thus, a focused investigation of pioneering scientists appears warranted.

PIONEERS IN NEURAL NETWORK RESEARCH

The present study was undertaken in order to understand in greater detail what factors influence pioneers in their choice of a research agenda and their persistence in the field. We selected as the basis for this examination the field of neural networks research, which is one of nearly a dozen fields of science and technology that we are studying concurrently. The decision to examine neural networks holds no special significance other than the opportunity to do so presented itself first. After a preliminary investigation of the neural network field, we concluded it would be interesting to conduct a comprehensive study with a primary focus on pioneering researchers.

A neural network is a type of information processing system that is inspired by models of the human brain. By using a biological model in its design, a neural network system has certain features that make it unique in form and function from conventional computers. For example, a neural network is not programmed in the usual sense, but rather it is trained with data. This implies that the computational performance of a neural network improves with experience: as it processes more and more information in performing a task, it becomes increasingly more accurate in its response. Another feature is its degree of parallelism in processing a task. Unlike a normal computer with a single or small number of sophisticated central processing units, a neural network has a very large number of simple processing elements that operate simultaneously on a computational problem. These features allow it to perform certain tasks that otherwise might be very difficult using existing computer technology. Neural networks are also referred to as connectionist systems, adaptive systems, or neurocomputers. For further details, refer to the recent report by DARPA (1988).

Neural networks have a long history of development, stretching back to theoretical explanations of the brain and cognitive processes proposed during the 1940s. In the early years, researchers formulated and elaborated upon basic models of neural computing that they then used to explore phenomena such as adaptive stimulus-response relations in random networks. By the 1960s there were several efforts to implement neural networks, the most notable being the single-layer "perceptron." Among neural network researchers the perceptron was considered a watershed, but at the same time it served as a lightning rod for criticism from researchers more interested in the burgeoning field of artificial intelligence. The idea of neural networks, as exemplified by the perceptron, quickly became seen as almost antithetical to the symbolic reasoning principles of artificial intelligence. Critical analysis of the perceptron led some highly respected AI researchers to proclaim that the concept was fundamentally flawed, and as such, inappropriate for researchers to waste much effort on the subject. By casting doubt as to its legitimacy, antagonists of neural networks may have effectively dissuaded other researchers from entering the field in larger numbers (Minsky and Papert, 1988).

The controversy surrounding neural networks notwithstanding, work continued during the early 1970s with perhaps no more than a few hundred researchers worldwide in the field. Undeterred in their belief of the potential of neural networks, their persistence over the next decade eventually paid-off. By the 1980s, neural networks began to be viewed in a new light by researchers in a variety of disciplines, such that the field soon achieved a

position of legitimacy within the scientific community. A professional society for neural network researchers was formed, specialized journals and books were published, and the first in a series of international conferences were held. While it is difficult to explain exactly why the perception of the field changed so dramatically, at least four important technical events can be discerned: (1) the evolution of the single-layer perceptron into a multi-layer system; (2) the rapid development of related technologies that enabled researchers to develop, simulate, and diagnose neural networks of greater sophistication; (3) significant progress in theoretical understanding of neuro-biological processes; and (4) the contributions of researchers pursuing the idea of parallel distributed processing, the so-called PDP-group. In light of these developments, as well as others, interest in the field became widespread, such that the number of researchers working on neural networks expanded rapidly. By the end of the decade the size of the field swelled in membership from a few hundred to several thousand researchers worldwide.

The evolution of the neural network research community is not unusual and may even be typical of emerging fields in some of its sociological characteristics. It is fairly common for new fields to lack widespread acceptance for long periods, sometimes attracting controversy, other times simply being ignored by researchers. But when they do catch on, fields tend to grow rapidly. This pattern has occurred, to greater or lesser extent, in each of the dozen fields we have examined so far. Given the recent experience within the field of neural networks, this case presents us with an excellent opportunity to examine in great detail the behavior of pioneering researchers relative to large numbers of researchers who follow in their footsteps.

METHOD

Through an analysis of published sources, including books, journal articles, and conference proceedings for the two-year period from 1988 to 1989, we identified more than 3,000 researchers worldwide working on the subject of neural networks. From this material, we were able to determine the exact address for each of 2,037 researchers in thirty-five different countries. Given the scope of the research community, a survey questionnaire was determined to be the most appropriate method of investigation. A twelve-page questionnaire in English was sent to researchers inquiring about (a) their neural network activities, (b) their decision to begin working on neural networks, (c) factors that might lead them to cease their neural network research in favor of another problem area, (d) their interaction with the rest of the neural network research community, and (e) their

demographic characteristics. The questionnaire was pretested in the United States. Additional tests were conducted in Europe to reduce potential interpretational difficulties arising among those respondents for whom English is a second language.

Since there were thirty-seven researchers with more than one address during the time period considered, a total of 2,074 questionnaires were mailed in February 1990. After the third week of data collection, we mailed a follow-up letter and posted e-mail messages on computer bulletin boards to alert neural network researchers of the survey. Of the 2,074 questionnaires, 162 were returned as undelivered by the post office. None of the thirty-seven researchers with more than one address were represented in the undelivered questionnaires. At the completion of the data collection period approximately ninety days later, 720 of the 1875 questionnaires presumed to be delivered were completed and returned, yielding a final response rate of 38.4 percent. Some of the factors that may have affected the response rate include: the length of the questionnaire, the global scope of the survey, and the institutional mobility of researchers.

DATA

Validity checks

In order to rule out apparent self-selection biases, demographic comparisons were made to determine whether the survey population departs significantly from the respondent sample. In particular, first-order comparisons between the two groups were made with respect to the geographic location of a respondent's institutional affiliation, type of institutional affiliation, and disciplinary background.

First, a geographic comparison was made clustering the respondent sample and the survey population into four regions: the Americas, Europe, the Far East, and the Middle East. Of the 720 respondents, 63 percent reside in the Americas (all but a few percent in the U.S.), 25 percent in Europe, ten percent in the Far East, and about two percent in the Middle East (mainly Israel). These percentages coincide almost perfectly with the survey population ($\chi^2=5.24$, d.f.=3, n.s.). Similar results were achieved when omitting the smallest category (the Middle East) from the test.

A second test compared the respondent sample and survey population with respect to the institutional affiliation. Respondents were classified into three categories: universities, commercial firms, or other types of institutions (mostly government funded laboratories that are not university-based). Among the 720 respondents, 452 (63 percent) are affiliated

with academic laboratories, 177 (25 percent) are employed in commercial firms, while 91 (12 percent) are engaged in other types of institutions. A comparison reveals that no statistically significant departure exists between the respondent sample and the survey population ($\chi^2=5.61$, d.f.=2, n.s.).

A final, albeit less precise, test compared the disciplinary background of the sample respondents with those of the survey population. Although respondents indicated their disciplinary backgrounds, for the survey population we were only able to infer researchers' disciplines from their postal address when a departmental affiliation was provided (e.g., researchers belonging to electrical engineering departments were classified as electrical engineers). Upon careful inspection of the survey population, the disciplinary background for about 1,500 researchers were found. Using this data, we were unable to find a significant difference when comparing respondents with the survey population. The disciplines most represented among respondents include electrical engineering (36 percent), physical sciences (19 percent), computer science (18 percent), biological sciences and engineering (7 percent), mathematics (7 percent), and psychology and cognitive science (5 percent).

Sample characteristics

The 720 respondents are employed in 220 different academic institutions, 101 commercial firms, and 62 other (mostly governmental) types of organizations. There are 89 respondents who report more than one employer. The large majority of respondents (82 percent) hold a doctorate or are in the process of obtaining one. Only 16 percent report holding a master's as their highest academic degree, and just two percent are at the level of a bachelor's degree. The distribution of academic degrees is further reflected in the respondents' current positions of employment. The majority of them are university faculty (38 percent) or hold a scientific post (32 percent), ranging from staff scientist to chief scientist. About 17 percent of the respondents are students, virtually all of whom are in doctoral programs. Regarding other employment positions, only seven percent of the respondents report themselves as being an engineer, while just five percent are managers. The remaining few percent of respondents fall into several other employment categories.

The average respondent is 37 years old (s.d.= 9.2 years). The respondent sample ranges in age from 22 years for the youngest to 69 years for the oldest, with the youngest quartile between ages 22 and 30 and the oldest quartile between ages 43 and 69. The median age is 35 years. For the 702 respondents who specified the year they began working on neural

networks, the average length of time in the field is 6.2 years, (s.d.= 6.1 years). The median length of time in the field is four years, with the range between one and 40 years. A variable measuring the length of a respondent's professional experience (not necessarily in the field of neural networks) was created based on the time elapsed since graduating with the highest degree. The average length of professional experience is 8.7 years (s.d.= 8.8 years). The median number of years is six, with a range from zero (i.e., students and recent graduates) to 46 years. The quartile with the least professional experience has between zero and one year of experience; the one with the most experience has between 14 and 46 years.

Identifying pioneers

Since the focal point of this study is on understanding the problem choice motives of pioneering researchers and their persistence in the field, identifying exactly who the pioneers *are* is a critical issue. Our determination of who in the respondent sample should be classified as a pioneer is based upon when a respondent enters the field of neural networks. As previously discussed, the evolution of the neural network community is marked by a period of rapid growth in membership during the 1980s and by the advent of a professional society, specialized journals and books, and an international conference. These events serve as indicators of the establishment of neural networks as a legitimate field of research within the broader scientific community. Thus, a point of demarcation for separating pioneering researchers from the rest of the sample should lie somewhere in this period.

The cumulative distribution of the entry year for each respondent, which is shown in Figure 1, illustrates the change over time in participation in the field. From this cumulative growth pattern it is clear that the field grew most rapidly from about 1984 onwards. The number of respondents entering the field each year was much lower during the 1960s and 1970s. About 25 percent of the respondents entered the field prior to 1984, whereas about 75 percent of them entered from 1984 to 1990. Both the historical overview of neural network research and the entry pattern illustrated in Figure 1 suggest that the point of demarcation for identifying pioneers is somewhere between 1980 and 1985. During the period from 1981 to 1984, a total of 91 respondents entered the field.

As a consequence of our analysis of historical events in the field, we decided to classify the 165 respondents (25 percent) who entered the field by 1983 as pioneers, while placing the remaining 537 (75 percent) who entered after 1983 into the control group. The control group provides us with a means for contrasting the responses of pioneers.

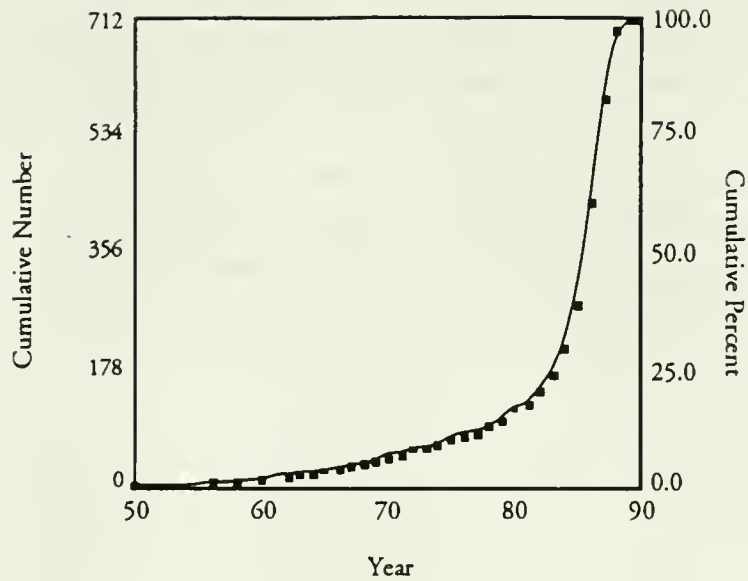


FIGURE 1: *Cumulative number of survey respondents entering the field of neural networks and cumulative percent.*

Pioneers and their decision to enter the field

We began our analysis of pioneers by examining respondents' motives for initially choosing neural networks as a problem area of research (see Appendix for core items). Respondents were asked to rate the degree of importance of numerous factors that might have influenced their decision to work on neural networks. The factors reflect the diversity of potential internal and external influences on researchers that have been discussed previously in the literature.

A first-order analysis based on t-test comparisons points to statistically significant differences between pioneers and the control group with respect to their motivations to enter the field in all but two of ten items (see Table 1). The strength of the differences between pioneers and the control group were further scrutinized using two control variables in an analysis of covariance procedure. Because we are interested in the factors that influenced a respondent's decision to enter the field, we used control variables that reflected the state of reality at the time the decision was made.

The first covariate concerns the respondent's professional experience at the time of entering the field. The average number of years of professional experience for pioneers before starting neural networks research is 2.3 years (N=156), compared with 4.9 years

<i>Importance of...</i>	PIONEER			CONTROL GROUP			t	p
	MEAN	S.D.	N	MEAN	S.D.	N		
intellectually compelling nature of field	6.27	1.2	157	5.71	1.5	525	4.93	***
positive opinions of leading researchers	3.13	1.9	152	3.81	1.9	518	-3.83	***
successes of other researchers	3.06	1.9	154	4.26	1.8	521	-7.07	***
potential for peer recognition	2.95	1.7	149	3.30	1.8	511	-2.15	*
dissatisfaction with previous research	2.79	2.0	152	2.92	2.0	514	-0.72	n.s.
opportunity to solve a societal problem	2.74	2.0	152	2.67	2.0	513	0.39	n.s.
availability of funding	2.07	1.6	151	2.60	1.9	514	-3.55	***
lack of other research topics	1.92	1.5	151	2.51	1.8	515	-4.12	***
potential for financial rewards	1.73	1.3	150	2.18	1.7	513	-3.51	**
opportunity to build company	1.60	1.2	151	1.83	1.5	514	-1.94	*

TABLE 1: *First-order t-test comparison of factors influencing respondent's decision to enter the field.*

Notes:

IV: pioneer/control.

Scale: 1 = not important; 7 = very important.

p-values: *** p<.001
 ** p<.01
 * p<.05

($N=518$) for the control group ($p_{\text{diff.}} < .001$). It is particularly interesting to note that a disproportionate number of pioneers entered the field prior to receiving their highest academic degree; that is, while they were students. A total of 98 of the 156 pioneers (63 percent) entered before graduation and another 11 entered the same year in which they graduated. In comparison, 200 of the 518 respondents (39 percent) in the control group entered before graduation and another 41 entered the year of graduation. This distribution is significantly different across both groups ($\chi^2=29.6$ with d.f.=2 and $p < .001$).

The second covariate concerns the respondent's age at the time of entering the field. On average, pioneers are four years younger in age when beginning work on neural networks than respondents in the control group. The average age at entry for pioneers is 27.8 years ($N=160$), compared with 31.8 years ($N=532$) for the control group ($p_{\text{diff.}} < .001$). The Pearson correlation coefficient among the control variables ($r = .85$) is significant ($p < .001$). The results of the analysis of covariance with each covariate are shown in Table 2. The data show that the first-order differences reported in Table 1 are sustained in the case of both control variables. Thus, we find further support for treating pioneers as a distinct group.

The main result from the analysis of entry items is that substantial differences between pioneers and the control group can be found, despite the apparent differences in their age and professional experience. In other words, the analysis enables us to answer the question of whether or not the first-order differences indicated in Table 1 reflect changes in the motives of researchers who are attracted to the field once it has gained legitimacy, or merely changes in the demographic characteristics of researchers. The analysis of covariance clearly shows that the factors influencing pioneers in entering the field cannot be explained solely in terms of differences in age or professional experience relative to respondents in the control group.

The proposition that pioneers are a distinct group of individuals received further support when examining two sets of questions concerning the characteristics of the field (see Table 2). One set of questions pertains to the influence of the field's size and growth rate on the entry decision, while the other set pertains to the financial cost of doing research in neural networks and the amount of specialized knowledge required to work in the field. It appears that perceptions about community size and growth rate have a different influence on the decisions of pioneers to enter the field. Once again, statistically significant differences remain even after controlling for the respondent's age and professional experience at the time of entry. Using the same analytical approach, we investigated the

<i>Importance of...</i>	PIONEER			CONTROL GROUP			PROFESSIONAL EXPERIENCE AT TIME OF ENTRY		AGE AT TIME OF ENTRY	
	MEAN	S.D.	N	MEAN	S.D.	N	p(IV)	p(cov)	p(IV)	p(cov)
intellectually compelling nature of field	6.30	1.1	149	5.69	1.5	509	***	n.s.	***	n.s.
positive opinions of leading researchers	3.10	1.9	146	3.81	1.9	502	***	*	***	n.s.
successes of other researchers	3.00	1.9	146	4.26	1.8	506	***	n.s.	***	**
potential for peer recognition	2.97	1.7	144	3.31	1.8	496	*	n.s.	*	n.s.
dissatisfaction with previous research	2.78	2.0	145	2.92	1.9	500	n.s.	n.s.	n.s.	n.s.
opportunity to solve a societal problem	2.78	2.1	145	2.67	2.0	497	n.s.	n.s.	n.s.	n.s.
availability of funding	2.07	1.6	145	2.60	1.9	498	**	n.s.	**	n.s.
lack of other research topics	1.94	1.5	145	2.49	1.8	499	***	*	***	n.s.
potential for financial rewards	1.74	1.3	144	2.20	1.7	498	**	n.s.	**	*
opportunity to build company	1.61	1.2	145	1.84	1.5	499	n.s.	n.s.	n.s.	*
growth rate of field at time of entry	2.18	1.7	153	3.92	1.9	511	***	n.s.	***	*
size of field at time of entry	1.96	1.4	153	3.05	1.6	510	***	n.s.	***	n.s.
intellectual entry requirements	3.78	2.2	152	3.73	2.0	509	n.s.	n.s.	n.s.	n.s.
financial entry requirements	2.45	1.7	150	2.42	1.7	508	n.s.	n.s.	n.s.	n.s.

TABLE 2: *ANCOVA of factors influencing respondents' decision to enter the field.*Notes:

IV: pioneer/control.

Scale: 1 = not important; 7 = very important.

Covariates: professional experience at entry, age at entry.

Group means are reported for the run with professional experience as control, for the other run the number of cases changes slightly, though group means only change at the second digit level.

p-values: *** p<.001

** p<.01

* p<.05

influence of financial and intellectual requirements on the respondent's entry decision. As shown in Table 2, no difference could be found between groups with respect to these factors.

For all of the analysis so far reported, we repeated the procedures omitting respondents who were doctoral students or recent graduates at the time of the survey. The differences found in the original analysis persist with one deviation ("potential for peer recognition" is non-significant, with $p=.053$), thereby ruling-out the possibility that a large number of students in the control group may adversely affect the response pattern.

In a final series of questions, the respondent's work environment when entering the field was examined in terms of the support and encouragement of colleagues and supervisors (if there was one at the time). The results of the first-order t-tests are shown in Table 3. The data indicate no difference between pioneers and the control group insofar as the awareness of colleagues or supervisors is concerned. Although there is a difference in terms of encouragement from supervisors, this difference is no longer statistically significant when students and recent graduates are omitted from the analysis. With respect to collegial encouragement from within the respondent's organization, there is no difference between the two groups. However, encouragement from colleagues outside the respondent's organization is statistically significant, even after omitting students and recent graduates. In addition, when controlling for age and professional experience in analysis of covariance tests, the difference remains statistically significant. Respondents in the control group report receiving more encouragement from colleagues outside their organization than pioneers do.

The persistence of pioneers

Careful examination of the historical development of the neural network community, as well as other fields, shows that not all researchers—including those who enter early—persist in their commitment to a field. Therefore, by itself, the decision to enter a field, while important, is not sufficient for understanding pioneering behavior. Given the proposition that pioneers enter early and stay with it, we investigated the influence of various internal and external factors that might lead a respondent to cease working on neural networks (see the Appendix). Examining the issue of persistence also enabled us to investigate pioneers in terms of their present attitudes—something that is not possible

<i>Respondent's work environment at entry:</i>	PIONEER			CONTROL GROUP			t-TESTS		PROFESSIONAL EXPERIENCE AT ENTRY		AGE AT ENTRY	
	MEAN	S.D.	N	MEAN	S.D.	N	t	p	p(IV)	p(cov)	p(IV)	p(cov)
awareness of supervisor ^a	5.00	2.2	116	5.10	2.1	364	.5	n.s.	n.s.	**	n.s.	**
awareness of colleagues	4.12	2.0	145	4.19	1.9	500	.4	n.s.	n.s.	n.s.	n.s.	n.s.
supervisor encouragement ^a	5.16	1.8	116	5.52	1.6	363	2.1	*	**	**	**	***
encouragement of colleagues inside organization	4.28	1.5	161	4.47	1.5	527	1.4	n.s.	n.s.	n.s.	n.s.	n.s.
encouragement colleagues outside organization	4.02	1.4	161	4.33	1.3	517	2.6	**	*	n.s.	**	n.s.

TABLE 3: *T-test comparisons regarding awareness and encouragement of respondent's colleagues and supervisor when entering the field.*

Notes:

Scale: 1 = not at all; 7 = very much.

N's reported for t-tests.

P-values are one-tailed.

^aOnly those respondents who had a supervisor at time of entry.

p-values: *** p<.001

** p<.01

* p<.05

when inquiring about past decisions to enter the field. Thus, there is a complementarity to the entry and exit motive questions, which is important to the design of the study.

The results of the first-order t-test comparisons are shown in Table 4. The data indicate statistically significant differences between pioneers and the control group for all items but one. When omitting students and recent graduates from the analysis, the results remain unchanged. Moreover, an analysis of covariance using the respondent's age and professional experience provides further evidence confirming the first-order differences between groups, with the only exceptions being the "overcrowding of the field" and, to a lesser extent, the "increased cost of research." (see Table 5).

It should be noted that, contrary to the previous analysis of covariance in which we used age and professional experience at the time the respondent entered the field, we now use the respondent's present age and professional experience as covariates. The average age of pioneers is presently 42.3 years (s.d.= 8.7), compared with 35.1 years (s.d.= 8.3) for the control group ($p_{\text{diff.}} < .001$). The average number of years of professional experience for pioneers is presently 13.4 (s.d.= 9.7), compared with 7.2 years (s.d.= 7.9) for the control group ($p_{\text{diff.}} < .001$). The Pearson correlation coefficient between covariates is .87 ($p < .001$).

Another question addresses how long the respondent is willing to continue working in the field, given the current rate of progress. Admittedly, this is a rather difficult question to pose and answer, but it does serve as a rudimentary indicator of how committed the respondent is to the subject of neural networks. The findings confirm the results reported in Table 5. A first-order Mann-Whitney non-parametric test reveals that pioneers report a willingness to persist longer with their neural network research agenda than the respondents in the control group: a median of five-to-ten years as opposed to two-to-five years ($p < .001$). Furthermore, controlling for age and professional experience, Mann-Whitney comparisons were repeated by grouping the respondents into "cohorts" based on age and experience (Table 6). Each cohort consists of 20 percent of the respondent sample. The results of this analysis show that in the case of each cohort, the difference between pioneers and the control group is statistically significant, with the exception of COHORT1 based on professional experience ($p = .068$). When examining the median for both groups within each cohort, it is apparent that pioneers intend to continue longer in the field than their colleagues in the control group do. The 20 percent cohort criterion was changed to 25 percent, with similar results.

<i>Importance of. . .</i>	PIONEER			CONTROL GROUP			t	p
	MEAN	S.D.	N	MEAN	S.D.	N		
diminished intellectual challenge	5.30	1.9	151	5.36	1.6	519	0.32	n.s.
lack of funding	4.05	2.0	162	4.66	1.8	519	-3.66	***
increased cost of research	3.69	1.8	155	4.02	1.6	513	-2.19	*
rapid progress in alternative areas	3.33	1.8	159	4.14	1.7	519	-5.13	***
difficulty in keeping up	3.20	1.7	157	3.74	1.7	517	-3.49	***
overcrowding of the field	3.22	1.7	157	3.50	1.7	519	-1.88	*
slow progress in problem solving	3.10	1.7	159	4.00	1.7	521	-5.87	***
negative opinion of supervisor ^a	2.82	1.6	65	3.85	1.8	350	-4.27	***
discontinuance at organization	2.75	2.0	148	3.87	2.1	501	-5.83	***
lack of financial rewards	2.70	1.7	155	3.23	1.8	516	-3.29	***
diminished interest among others	2.62	1.5	159	3.32	1.6	520	-5.02	***
unfavorable opinion of leading researchers	2.25	1.4	158	3.10	1.6	520	-6.57	***

TABLE 4: *First-order t-test comparison of factors that might influence respondent's decision to leave the field.*

Notes:

IV: pioneer/control.

Scale: 1 = not important; 7 = very important.

^arespondents who do not have a supervisor at the time of the survey are omitted from the analysis.

p-values: *** p<.001

** p<.01

* p<.05

<i>Importance of . . .</i>	PIONEER			CONTROL GROUP			PROFESSIONAL EXPERIENCE AT PRESENT		AGE AT PRESENT	
	MEAN	S.D.	N	MEAN	S.D.	N	p(IV)	p(cov)	p(IV)	p(cov)
diminished intellectual challenge	5.32	1.9	143	5.35	1.7	503	n.s.	n.s.	n.s.	n.s.
lack of funding	4.07	2.0	154	4.68	1.8	503	**	*	**	n.s.
increased cost of research	3.71	1.8	147	4.01	1.6	497	n.s.	n.s.	*	n.s.
rapid progress in alternative areas	3.30	1.8	151	4.14	1.7	504	***	n.s.	***	*
difficulty in keeping up	3.21	1.7	149	3.73	1.7	501	**	n.s.	**	n.s.
overcrowding of the field	3.21	1.7	149	3.48	1.7	503	n.s.	**	n.s.	*
slow progress in problem solving	3.10	1.7	151	4.01	1.7	505	***	n.s.	***	*
negative opinion of supervisor ^a	2.80	1.6	64	3.83	1.8	337	***	*	***	*
discontinuance at organization	2.78	2.0	141	3.86	2.1	485	***	***	***	***
lack of financial rewards	2.71	1.7	147	3.24	1.8	500	*	**	**	n.s.
diminished interest among others	2.65	1.5	151	3.33	1.5	504	***	n.s.	***	*
unfavorable opinion of leading research.	2.29	1.4	150	3.11	1.6	504	***	***	***	***

TABLE 5: *ANCOVA of factors that might influence respondent's decision to leave the field.*

Notes:

I.V.: pioneer/control.

Covariates: professional experience, age.

Scale: 1=not important; 7=very important

Group means are reported for the runs with professional experience as control, for the other run the number of cases changes slightly, though group means only change at the second digit level.

^arespondents not having a supervisor at the time of the survey were omitted from the analyses.

p-values: *** p<.001

** p<.01

* p<.05

	AGE (cell numbers = N)										PROFESSIONAL EXPERIENCE (cell numbers = N)									
	COHORT 1 (22-29 yrs)		COHORT 2 (30-33 yrs)		COHORT 3 (34-38 yrs)		COHORT 4 (39-44 yrs)		COHORT 5 (45-69 yrs)		COHORT 1 (< 1 yr)		COHORT 2 (1-4 yrs)		COHORT 3 (5-9 yrs)		COHORT 4 (10-16 yrs)		COHORT 5 (17-46 yrs)	
	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C
<i>years willing to continue with research agenda:</i>																				
less than 1 year	0	13	0	5	3	6	0	3	0	2	0	10	0	10	1	5	2	1	0	2
1 to 2 years	0	30	2	27	1	15	5	9	6	10	2	25	1	23	2	17	5	12	4	8
2 to 5 years	1	<u>42</u>	6	<u>71</u>	5	<u>33</u>	9	<u>45</u>	11	<u>32</u>	3	<u>47</u>	4	<u>61</u>	8	<u>45</u>	7	<u>42</u>	9	<u>38</u>
5 to 10 years	2	23	3	16	4	20	8	12	13	16	1	17	5	23	4	17	10	15	8	13
> 10 years	4	31	9	9	12	12	19	12	30	9	5	27	11	14	13	8	17	13	26	8
Mann-Whitney z	-2.5704		-3.6747		-2.5608		-3.5399		-4.6746		-1.4838		-4.4378		-3.5565		-2.7676		-4.6767	
One-tailed p	**		***		**		***		***		n.s.		***		***		**		***	

TABLE 6: Mann-Whitney tests on length of time respondent is willing to continue with research agenda using cohorts based on age and professional experience.

Notes:

P = pioneers; C = control group

Median values are underlined.

Each cohort contains ± 20 percent of respondents.

p-values: *** p<.001

** p<.01

* p<.05

A final question asks respondents to indicate whether neural networks is their only research interest, a major interest, one of several interests, a minor interest, or just an interest in keeping informed. From this question, it is possible to ascertain the relative stature of neural networks research to other problem areas for pioneers and the control group. Table 7 shows that pioneers more frequently report neural networks as their primary or major research interest. A Mann-Whitney test indicates that this difference is statistically significant ($p=.0012$).

<i>Neural network research is</i>	PIONEER		CONTROL GROUP	
	N	%	N	%
my only research interest	26	15.8	60	11.2
my major interest, though not the only topic on my research agenda	83	50.3	214	40.1
one of several interesting research avenues I pursue	48	29.1	223	41.8
a minor issue on my research agenda	7	4.2	25	4.7
a topic to keep informed about, without becoming actively involved	1	0.6	12	2.2

TABLE 7: *Respondent's degree of involvement with neural networks.*
(Mann-Whitney $z = -3.2360$; two-tailed $p=.0012$).

Sensitivity analysis

The analysis thus far provides substantial empirical evidence to support the premise that pioneers should be treated as a distinct group of individuals. Nonetheless, we re-examined the main entry and exit items, this time comparing pioneers who entered the field prior to 1980 ($N=95$) with respondents in the control group who started after 1984 ($N=486$). By omitting respondents who entered the field during the intervening five-year period, we avoid the need for a precise (perhaps artificial) demarcation for identifying pioneers. The results of the analysis confirm, item for item, the previous findings.

Furthermore, a discriminant analysis using several groups of questionnaire items as independent variables was performed to evaluate the sensitivity of each of the four years from 1981 to 1984 as a demarcation point for separating pioneers from the rest of the respondent sample. The discriminant analysis was run twice for each of the four years: once using a stepwise entry method and once using a hierarchical entry method. No matter

which of the two approaches is used and no matter what year is chosen to identify pioneers, the overall results remain the same. All of the discriminant functions are statistically significant ($p < .001$). Regardless of the year used to create the pioneer group, we consistently obtain a Wilks' λ of about 0.88 on the entry motive items and about 0.89 on the exit motive items. This suggests that the choice of the cut-off year is robust across the relevant time interval.

DISCUSSION

The forgoing analysis provides some insight into the character of pioneers and how they differ from colleagues in their decision to enter and persist in a field of research. With respect to the choice of neural networks as their problem area, pioneers are more deeply influenced by the intrinsic appeal of the subject matter than are respondents in the control group. The “intellectually compelling nature of the field” is in fact the only item that pioneers rate more highly than the control group ($p < .001$). In the same vein, pioneers are less influenced than the control group by a lack of other topics ($p < .001$) when choosing neural networks. This result shows clear support for the internalist argument that sees cognitive influences as the predominant factor in a researcher's choice of problem area. Pioneers are far less concerned with what is happening in the rest of the research community when deciding to enter the field. For example, pioneers rate as significantly less important: “positive opinions of leading researchers” ($p < .001$), “success of other researchers” ($p < .001$), and “potential for peer recognition” ($p < .05$). Pioneers are also less influenced by the size and growth rate of the field (in both cases, $p < .001$). Furthermore, they are less influenced by practical matters, such as the availability of funding ($p < .001$) and the potential for financial rewards ($p < .01$).

Pioneers appear to follow more closely the classic textbook explanation of problem choice in science. In contrast to the control group, they are drawn to the field by their intellectual interests and are rather oblivious to the social forces at play in the research community. Moreover, even though pioneers are predominantly students when entering the field, the first-order results remain after controlling for age and professional experience with one exception: eliminating the weak significance of “opportunity to build a company.” Thus we can rule-out the presumable youth and professional inexperience of students as a plausible explanation for the differences we find in the problem choice motives of pioneers. It is not simply a case of youthful idealism, but rather something else that is at the heart of pioneering behavior.

While the evidence with respect to the respondent's decision to enter the field strongly favors a view of pioneers as a distinct group, the fact that this decision was made several years prior to the survey is an important consideration. The passage of time since entering the field may distort perceptions of what has in fact influenced a pioneer's decision to work on neural networks. Are pioneers simply remembering things differently? Undoubtedly, the element of time makes pioneering behavior all the more difficult to understand. However, by examining the persistence of pioneers, we are able to complement the analysis of problem choice with an analysis of situational perceptions that are contemporaneous with the survey period for all respondents.

The uniqueness of pioneers as a group can be seen equally as clear in their response to the importance of factors that might lead them to leave the field of neural networks. Pioneers are different from the control group in every respect but one. Although there is no statistical difference with respect to the importance of diminishing intellectual challenge, pioneers consistently show less concern regarding all other factors. Even so, pioneers seem to be motivated by the intrinsic qualities of neural networks as an intellectual endeavor and to be single-minded in their determination. Neither slow progress in solving problems ($p < .001$), nor rapid progress in alternative fields, has as much importance to them as it does to the control group ($p < .001$). Regarding communal factors, pioneers are less influenced by the lack of interest among other researchers ($p < .001$) or the unfavorable opinions of leading researchers ($p < .001$). Furthermore, the lack of funding, lack of financial rewards, negative opinions of supervisors and the discontinuance of neural networks at the respondent's organization are each significantly less important to pioneers (in all cases, $p < .001$). Here again, as with the decision to enter the field, the results are not substantively changed when considering the respondent's age and length of professional experience.

Pioneers have a passion for their chosen subject, which is also born-out in their intent to remain in the field. Not only is their interest less diminished by a number of factors, but pioneers also intend to endure in the field for a longer period of time. When divided into cohorts and controlling for age and professional experience, we find that pioneering cohorts, in all but one case, express a longer term commitment to the field of neural networks. The evidence further shows that most pioneers are more focused on neural networks, considering it their major, if not their only, research interest.

The broad picture of pioneers that emerges from the data is fairly consistent. When choosing an area of research, pioneers are more influenced by their own perceptions of what is intellectually interesting and less concerned with the actions and opinions of others, as

well as the practical realities of funding and rewards. Likewise, with respect to their persistence in the field, pioneers are equally single-minded in their perspective. While the evidence seemingly supports the internalist view of the primacy of cognitive influences in the problem choices of pioneering scientists, the findings also have implications for understanding the motives of scientists who enter a field once it is legitimated. The evidence suggests that it is with this group that social forces, both internal and external to the community, play a larger role in problem choice.

The exploratory nature of this investigation must be emphasized. First, although the results in the case of the neural networks research community are compelling, further work is required to test the external validity of these findings. To this end, two other research communities are currently being examined. Second, understanding the subtle behavior of pioneers is quite difficult in the context of a cross-sectional survey such as this one. Instead, what is required is a long term study of pioneering that follows the decision process of researchers over time. Given the large number of respondents, it is feasible to transform the initial survey into a longitudinal design by periodically following-up with the respondents to see if they remain in the field. We have already commenced work on such a follow-up study. Nonetheless, it is important to recognize the limitations of survey methods in examining pioneering behavior.

CONCLUSION

Pioneering researchers play a central role in the emergence of new fields of science and technology. The results of our analysis show that pioneers are unique in their motivations to enter and persist in their chosen field of neural network research. When compared with their colleagues, pioneers are found to be more influenced by their own perceptions of what is intellectually compelling and less influenced by the opinions and actions of others in the research community and by the availability of funding and rewards. After controlling for age and professional experience, these differences continue to hold, even though most pioneers in the sample were students when they entered the field.

The results of this study point to several avenues for further research. One avenue is to examine institutional differences in pioneering scientists and, in particular, the differences that exist between academic and commercial laboratories. Another avenue is to investigate the characteristics of students who pioneer a new field and how they are similar or dissimilar from that of their professorial colleagues.

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APPENDIX

Items inquiring into the respondent's decision to enter the field of neural networks:

How important were each of the following factors in influencing your initial decision to include neural networks in your research agenda (*respondents were asked to circle on a 1 (not at all important) to 7 (very important) -scale with midpoint 4 (somewhat important)*):

1. intellectually compelling nature of neural networks
2. lack of other promising research topics
3. availability of funding for neural networks research
4. potential for financial rewards
5. potential for recognition by peers
6. dissatisfaction with a previous research agenda
7. positive opinions of leading researchers in the field
8. successes of other researchers with neural networks
9. opportunity to build a commercial enterprise
10. opportunity to solve an important societal problem

Items inquiring into what might lead the respondent to leave the field of neural networks:

How important would each of the following factors be in diminishing your current interest in neural network activities (*respondents were asked to circle on a 1 (not at all important) to 7 (very important) -scale with midpoint 4 (somewhat important)*):

1. slow progress in solving technical problems in neural networks
2. lack of funding for your neural network research
3. diminished interest among other researchers in neural networks
4. rapid progress in alternative areas of research
5. opinions of leading researchers unfavorable to neural networks
6. negative opinion of your supervisor (if any) toward neural networks
7. discontinuance of neural net activities at your organization
8. lack of financial rewards
9. diminished intellectual challenge of neural network research
10. increased financial cost of conducting neural network research
11. overcrowding in terms of the number of neural network researchers
12. difficulty in keeping up with new developments in neural networks

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